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The use of geomembrane as a remediation towards a sustainable OMWW landfilling: case study of Agareb site in Sfax, Tunisia

Rakia S'habou[1], and *Zeineb* Ben Salem[1*]

[1] Univ.de Carthage, Institut Supérieur des Technologies de l'Environnement de
l'Urbanisme et du Bâtiment, 2 Rue de l'Artisanat Charguia 2 - 2035 Tunis, Tunisia.

Abstract. In Tunisia, olive mill wastewater (OMWW) locally named 'margine' constitutes a serious problem due to its huge amount, of about one million ton per year, and the high pollutant load resulting in the excessive chemical oxygen demand (COD) values and the presence of phytotoxic and antibacterial polyphenols. The most common treatment of OMWW was storage in evaporation ponds which are authorized but uncontrolled. Thus, it represents a potential contamination source of natural resources (air, soil and water) via infiltration. This study aims at a critically analysing the OMWW storage management on the site of Agareb in Sfax, Tunisia. The data relating to the OMWW production highlights that it exceeds its storage capacity due to the uncomplete OMWW evaporation. The geotechnical investigations confirmed the spread of OMWW through and below the storage basins. Furthermore, multiple slope sliding has been observed within embankments separating the OMWW storage basins. Faced with this alarming situation, the assessment of the incorporation of geomembrane is analysed in order to ensure the sustainability of OMWW landfilling. The slope stability analysis based on limit-equilibrium method (LEM) using Midas-Soil works software was investigated. The use of geomembrane can secure the slope stability and limit OMWW infiltrations in the landfill body and sub-soils in the studied site.

1 Introduction

In Tunisia, the olive industry, apart from its undeniable weight in the national economy, is among the main sources of environmental pollution due to the large quantities of olive mill wastewater (OMWW) locally named 'margine', and solid waste (pomace) which arise seasonally from the milling process. Indeed, the OMWW amounts to 1 million m^3 per year and has a very high organic load, recalcitrant in nature and with a high amount of toxicity compounds [1]. Several solutions have been examined for the management of this effluent such as biological treatment processes [2], additions in composting [3,4], ferti-irrigation [5] as well as valorization in the civil engineering field [6]. The storage of OMWW in evaporation ponds, which are authorized but unfortunately uncontrolled, remains the most adopted solution [1]. However, the assessment of the environmental effects of stored OMWW shows that it presents a potential contamination risk of natural resources: air, soil, surface water and groundwater [7,1, 8, 9]. Furthermore, there is a lack in studies dealing with effects of stored OMWW on geotechnical properties of sub-soils and embankments' stability in such sites.

Recent research studies employing geomembranes in controlled solid waste landfills have shown their effectiveness to enhance stability and prevent contamination in landfill body and sub-soils [10,11].

In this paper, a critical overview of the OMWW storage management focusing on slope stability is developed based on the previous works conducted by [12, 13] at the OMWW evaporation ponds of Agareb in the region of Sfax, Tunisia. In light of these findings, the efficiency of geomembrane implementation was analysed. The slope stability analysis was investigated based on limit-equilibrium method (LEM) using Midas-Soil works software.

2 Review on the OMWW evaporation ponds of Agareb

2.1 Location

The OMWW storage site is located in the area of Bou Ladhieb, 8 km west of the town of Agareb in the region of Sfax (Fig. 1). The site occupies an area of 50 hectares. It includes a reception basin (B1), different storage basins (Bi) whose surfaces vary from 3,217 to 11,919 m^2, and evaporation beds that spread over an area of about 214,607 m^2 [13].

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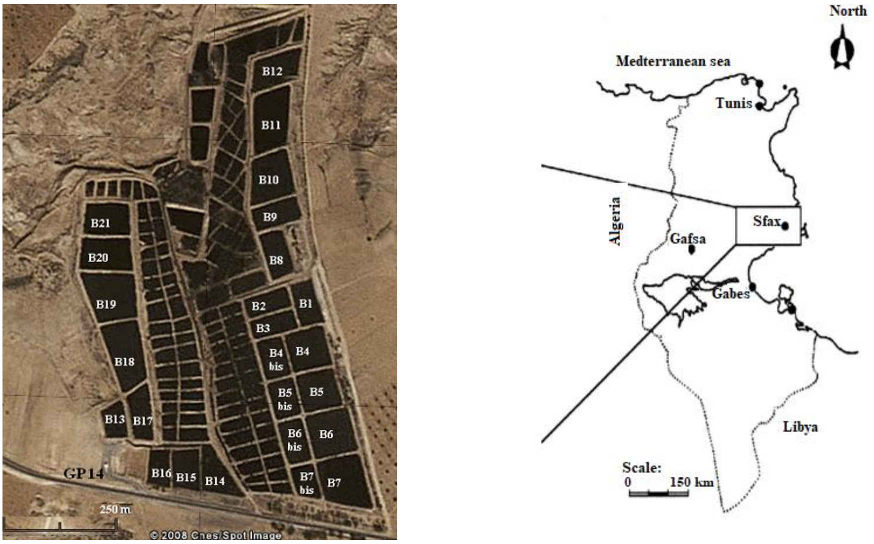
*corresponding author: zeineb.bensalem@gmail.com



(a)Location of OMWW ponds (b)Location of the studied area of Sfax in Tunisia

Fig. 1. OMWW evaporation ponds' location

2.2 OMWW storage management

2.2.1 OMWW production and storage capacity

The OMWW arising from the milling process amounts to 0.5–1.4 l/kg of olives depending on the process. In Tunisia, OMWW production is approximately 950,000 m^3 per year produced from 1000,000 tons of olives, averaging 0.95 litre/kg [14].

In the Sfax region, the mean annual OMWW production is almost 200,000 m^3 (fig. 2). In OMWW evaporation ponds of Agareb, despite the fact that storage capacity is in the order of 500,000 m^3 [13], the basins are not able to receive all the quantities generated since they have never been emptied due the uncomplete OMWW evaporation as required.

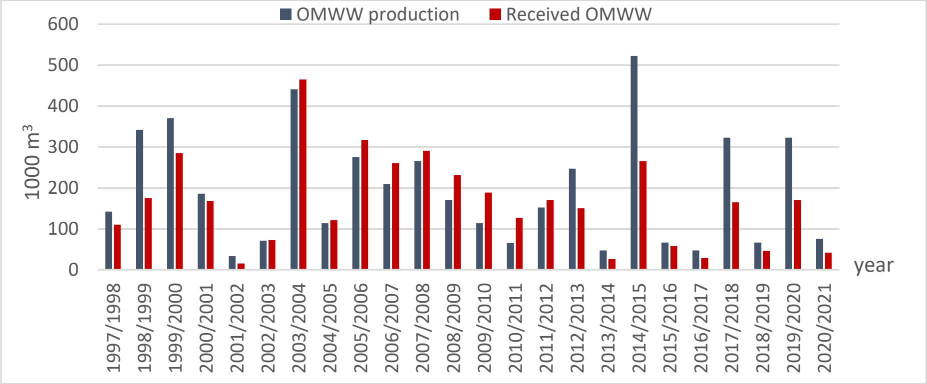


Fig.2. The evolution of the OMWW produced in the region of Sfax and those received in the site of Agareb since its creation until 2021 [14]

2.2.2 Physico-chemical characteristics of stored OMWW

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The stored OMWW is dark, foul-smelling. It is easily fermentable and has a high organic content of 11g/l with an excessive chemical oxygen demand (COD) values of about 70,000 mg/l. OMWW pH is acidic (= 6), its electrical conductivity is high and has free polyphenol concentrations that are phototoxic and anti-microbioal. The stored OMWW density is 1.02 and their suspensed solids are around 6g/l [13]. These properties prohibit the OMWW storage properly without any protection of the site.

2.2.3 The operational system of OMWW evaporation ponds

As soon as the tanks arrive on site, the OMWW are directly discharged into the reception basin B1. A siphoning system (Fig. 3) allows the OMWW transfer to the next storage basin (Bi) by gravity [13].

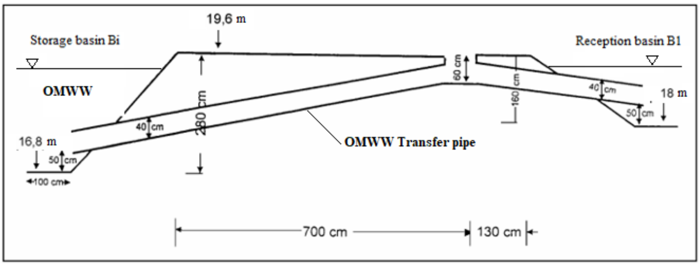

Fig.3. Initial design model of embankment [13]

Figure 3 shows the design geometry of the embankment separating storage basins with a high of almost 3 m, a width of 8.3 m. The embankment side slope angles were variable ranging from 30° to 50°.
It should be noted that the sub-base of storage basins is not protected by any active barrier, and not properly compacted as required in sustainable solid waste landfills [16].

2.3 Detected anomalies based on field observations

The field observations revealed a longitudinal fault line of 5cm thickness which corresponds to tensile cracks related to successive slides in the embankment separating OMWW storage basins (Fig. 4). Similarly, fine and branched transverse cracks have been detected [13].

Fig.4. Deteriorated embankment

Fig. 5. OMWW infiltration through embankment

The comparison of this actual embankments' geometry with that of the initial model design (Fig. 3) shows a pronounced failure of the embankment sides with an increase of slope angle reaching 60°, and an important reduction of the width.
Figure 5 highlights lateral and vertical OMWW spread through sub-soils especially in porous layers.

2.4 Assessment of OMWW evaporation ponds' stability

The purpose of slope stability analysis is to obtain a quantitative measure of slope stability in whole or in parts. Generally, it is expressed by the estimation of factor of safety (FOS), defined as the ratio of the available strength to the strength at failure. Datta [17] suggests that the value of safe safety factors to guarantee long-term slope stability of the landfill is 1.5-3.0.

Previous researches have been conducted in the OMWW disposal site of Agareb to assess the stability of embankments based on geotechnical investigations [12,13]. Thus, an excavation 'P' with 3 m depth was made at the embankment separating the OMWW storage basins B11 and B12 where cracks were detected at a distance of 1.5 m from the edge (Fig. 6).

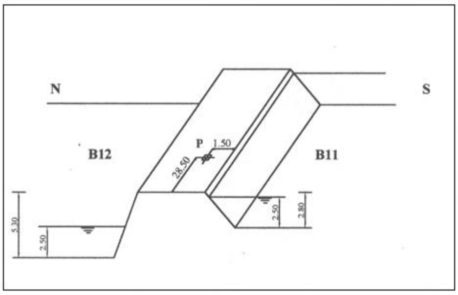

Fig.6. Location of the excavation 'P' [13]

The embankment soils were formed of two facies: sandy and clayey soils. Various identification tests were conducted on extracted samples. The results of soil laboratory testing are summarized in Table 1. The geochemical results showed the contamination of the embankment soils with infiltrated OMWW [12].

Table 1: Results of soil characterization [13]

Soil type	SC	CL1	SM	CL2
Depth (m)	0.4	0.9	1.7	2.6
Unit weight γ (kN/m^3)	17.4	16.2	16	17
Dry unit weight γ_d (kN/m^3)	15.9	15	15.2	14.7
Effective cohesion C' (kPa)	5	5	5	5
Effective friction angle φ'(°)	22	13	25	13

Previous researches were conducted by Shabou et al. (2005) [12] in the site of Agareb and the calculated factor of safety (FOS) in these existing conditions, using the Bishop method varied from 0.77 to 1.03 . These values mean that the slopes are in unstable conditions and need to be reinforced to prevent further landslides.

3 Remediation of OMWW landfilling using geomembrane

As required in sustainable solid waste landfills, a liner system consisting of multiple layers of clay or geosynthetics (mostly geomembranes) could be implemented to prevent movement of any liquid between the landfill and surrounding area. In general, geosynthetic liners can limit leakage infiltration more efficiently [16].

In light of the above results, as a remediation the incorporation of geomembrane can be proposed as an active barrier to stop further OMWW infiltrations on the deteriorated storage ponds of Agareb.

The first step consists on an emptying operation by completely removing the stored OMWW. After a solar drying of soils' embankment, geomembrane can be installed in the sub-bases of storage basins as well as in sides' embankment. Consequently, the stability of the embankment in dry condition could be enhanced.

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In order to assess the effectiveness of the geomembrane implementation on the studied site, the slope stability analysis is developed based on limit-equilibrium method (LEM) using the software Midas Soilworks 2020 version 1.1, according to two cases:

-Existing situation: embankment without geomembrane, i.e. saturated soils with infiltrated OMWW (saturated condition)

-Proposed remediation: embankment with the use of geomembrane as an impermeable element, i.e. dry condition without OMWW infiltration.

Fig.8 shows the actual geometry after successive slope sliding in the embankment, which was adopted in the following slope stability analysis. Geotechnical parameters for the soil layers are listed in Table 1.

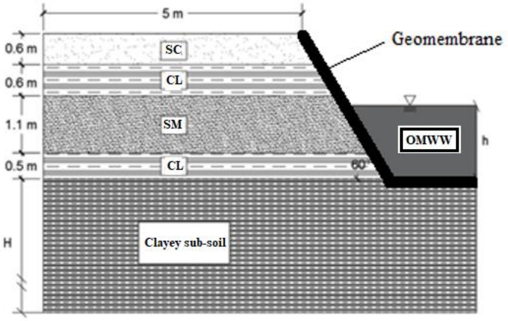

Fig.8. The geometry of the embankment separating basins B11 and B12 and geomembrane placement

Stability analyses performed for the embankment separating basins B11 and B12 according to relevant saturated conditions, indicate a minimum factor of safety of 0.72 leading to phenomena of loss of stability as shown in Fig 9. The factor of safety calculated at the observed tensile cracks located at a distance of 1.5 m from the edge (Fig.6) is 0.84. These results were in concordance with those found by Shabou et al. (2005) [12].
The use of geomembrane as an impermeable element in this case study seems to be efficient to enhance the slope stability. Indeed, a significant increase in the safety factor from 0.72 to 1.32 was obtained as shown in Fig.10.

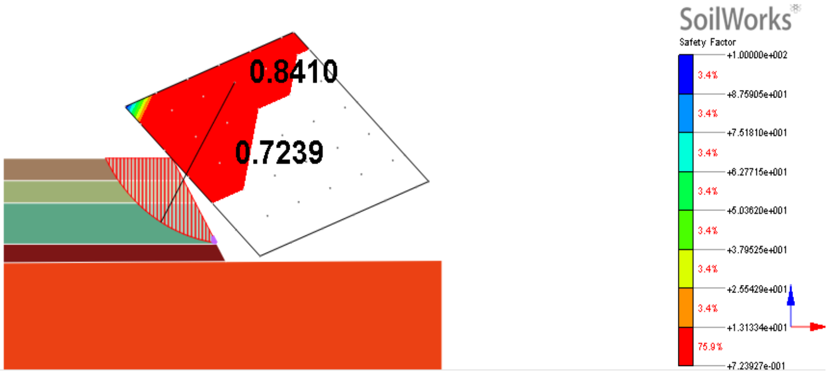

Fig. 9. Factor of safety in the actual situation with saturated soils

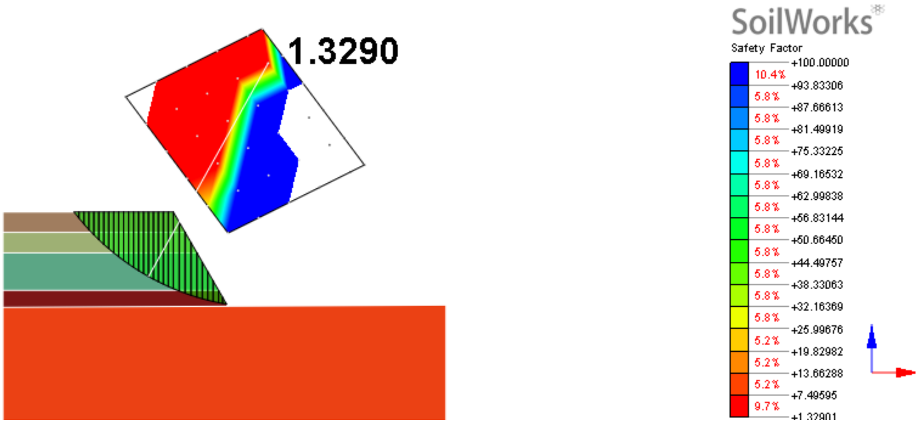

Fig.10. Factor of safety with use of geomembrane in dry condition

4 Conclusion

In this study, a critical analysis of the OMWW landfilling in the site of Agareb in Sfax is developed. Obtained results showed OMWW infiltrations and instability of embankment in the prevailing conditions.

As a remediation, the use of geomembrane is proposed as an active barrier against eventual OMWW infiltration in the landfill body and sub-soils. The slope stability analysis show that the implementation of geomembrane enhances the slope stability of the studied site and thus prevents slope failure.

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